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William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405

Human Factors Design Guide Update (Report Number DOT/FAA/CT-96/01): A Revision to Chapter 5 – Automation Guidelines

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Final Report and Guide

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16. Abstract

This document contains an updated and expanded version of the automation chapter of the Human Factors Design Guide (FAA, 1996). A research team of human factors experts evaluated the existing guidelines for relevance, clarity, and usability. The research team drafted new guidelines as necessary based on relevant sources and reorganized the document to increase usability. This resulted in extensive changes to the original document, including the addition of more than 100 new guidelines and 102 new sources. This report contains a brief introduction along with the modified guidelines.

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Executive Summary

The 1996 version of the Human Factors Design Guide (HFDG) consolidated multiple sources of human factors guidance and overcame limitations associated with using military standards and guidelines. Upon publication, the HFDG quickly became a key reference tool for the application of human factors policy to acquisitions and the development of new systems and equipment.

Researchers at the Federal Aviation Administration (FAA) William J. Hughes Technical Center have revised the original Chapter 5 – Automation of the HFDG. The revised version is an updated and expanded set of automation guidelines to meet the needs of FAA missions and systems. Although the original HFDG was primarily focused on FAA ground systems and equipment such as those managed and maintained by Airway Facilities, the researchers expanded the coverage beyond maintenance issues.

Researchers divided the revision process into several phases including the identification of source material, systematic evaluation of literature, reorganization of topic areas, and expert review. The revised chapter is limited in scope to human factors guidance related to automation. The complete set of new guidelines is contained in the appendix. The revision resulted in several changes, as follows.

a. The search for current information pertaining to automation resulted in the addition of 102 new sources.

b. The review of these source documents resulted in the addition of over 100 new guidelines that researchers incorporated into the revised document.

c. The reorganization of the revised chapter involved an extensive regrouping of information as well as the removal of redundant guidelines.

1. Introduction

The modernization of the National Airspace System (NAS) includes an increasing reliance on automation, particularly computer-based automation. Automation in the modern NAS is being used in more places and in more ways than previously considered, due largely to advances in computer technology along with decreases in computing costs. Automation has the potential to reduce workload, reduce errors, and increase efficiency. Improperly implemented or designed automation, however, can have the opposite effect, increasing workload, increasing errors, and decreasing efficiency. A current set of guidelines to use as a reference can benefit this process.

The original Chapter 5 on maintenance automation in the Human Factors Design Guide (HFDG) (FAA, 1996) contained information that was dated. A more modern set of guidelines was needed with an increased scope beyond just maintenance issues. This document summarizes the development of an updated and revised set of automation guidelines for the HFDG. Along with the introductory material briefly describing the creation process, this document contains the new guidelines as an appendix, complete with a table of contents, sources, and an index.

1.1 Purpose

The purpose of this document is to provide an updated and expanded set of automation guidelines that meets the needs of FAA missions and systems. Additional goals were to expand the coverage of the chapter for relevance beyond maintenance systems and to organize the document so that users can easily locate the needed information.

1.2 Scope

This document is limited in scope to human factors guidance related to automation. Although alarms and alerts are tied closely to automation, guidelines on auditory alarms and alerts are being consolidated into a separate chapter.

1.3 Shall and Should

Each guideline specified in Appendix A is identified as a "shall" or "should" statement. A solid, black square (▪) adjacent to the guideline identifies the "shall" statements. These originate from or are comparable to statements from authoritative sources such as those associated with FAA orders, standards, and military specifications.

Each "should" statement is identified by an open, white square (▫). These represent best practices guidance that is applicable in most cases but may involve trade-offs or be influenced by context-specific factors.

2. Method

Researchers organized the revision process into several phases including the review of original material, identification of new source material, systematic evaluation of literature, reorganization of topic areas, and expert review. During this entire process, the research team tried to provide a usable reference document. This meant ensuring that guidelines were based on credible sources and were stated as clearly and concisely as possibly, with minimal redundancy.

2.1 Review of 1996 Chapter on Maintenance Automation

In the first phase of the research effort, a research team from the NAS Human Factors Branch (ACT-530) carefully went through the original Chapter 5 on maintenance automation from the HFDG (Federal Aviation Administration (FAA), 1996). This original version contained several guidelines that were based on the personal experiences of previous authors. Guidelines such as these that could not be verified by outside, published material were deleted. Guidelines that were limited in scope to maintenance automation were rewritten where appropriate to expand applicability beyond maintenance. Other guidelines were revised as necessary to make them more concise or more understandable by allowing only one "should" or "shall" statement per guideline. Redundant guidelines were deleted.

2.2 New Source Material Identification

The research team identified and obtained automation source materials. Most of the information on automation came from disparate journal publications, technical reports, and books, with very little in the form of guidelines. The researchers evaluated the adequacy of the source material for inclusion in the revised design guide chapter and rejected documents that did not contain sufficiently relevant information.

2.3 Literature Evaluation

The research team compared new source material against the material in the original Chapter 5 on maintenance automation to identify areas where additional information was needed. When information from the new source documents warranted the creation of a new guideline, relevant material was written in the proper guideline format. The researchers attached the applicable references to each guideline and provided a list of sources at the end of the chapter. Information on automation proved much more difficult to make into guideline format than computer human interface information, thus, the guidelines in this chapter are often followed by extensive discussion paragraphs or examples to further clarify the guideline.

2.4 Reorganization

After adding all of the new material in guideline format and revising and updating the existing guidelines, researchers reorganized the topics and guidelines within the document to facilitate the location of information. They grouped related topics and created new chapter sections from areas that had been expanded due to new information.

The new set of guidelines are divided into 15 sections; general information, design and evaluation, system response and feedback, interface, user acceptance and trust, modes, monitoring, fault management, false alarms, training, function allocation/levels of automation, information automation, adaptive automation, decision aids, and control automation.

2.5 Expert Review

A draft of the revised Automation Chapter 5 was circulated among a select group of human factors professionals for their review and comment. An automation subject matter expert provided further review. These reviewers provided useful feedback on the chapter organization and the effectiveness, clarity, and relevance of the guidelines. The automation subject matter expert provided additional feedback on topic completeness and provided several additional source references. The research team addressed all of the comments, revising guidelines and obtaining additional references as necessary.

3. Document Overview

The revision of the HFDG (FAA, 1996) Chapter 5 document resulted in several mentionable changes. The search for current information pertaining to automation resulted in the addition of 102 new source references. The review of these source documents resulted in the addition of over 100 new guidelines that were incorporated into the revised document. The reorganization of the revised document involved a systematic regrouping of information as well as the removal of redundant or unverifiable guidelines.

The revised Automation Chapter 5, contained as an appendix within this document, provides a comprehensive set of usable human factors guidelines. As with any set of guidelines, those that are optimal for one situation may not be suitable for another situation due to the trade offs involved between some of the guidelines and context-specific influences. Consequently, these guidelines should be used in conjunction with the advice of a human factors expert.

The revised Chapter 5, as a part of the HFDG (FAA, 1996), is considered a living document. It will be updated as needed to keep current with emerging research, technological advances, and user feedback. This will provide the most current human factors knowledge in a usable tool.

In creating these guidelines, the researchers have tried to develop an easy to use, comprehensive reference document. Effort was made to reduce redundancy while providing clear, understandable guidelines. However, no document is without room for improvement. Constructive remarks on this document can be sent to the authors at the William J. Hughes Technical Center, Atlantic City International Airport, NJ 08405.

The update of HFDG (FAA, 1996) Chapter 5 represents one part of a larger scale effort to keep the guidance in the entire HFDG current. The revised Chapter 5 will be incorporated in the future release of a new HFDG CD-ROM.

The revised version of Chapter 5 is presented in Appendix A. A table of contents precedes the document. The guidelines are followed by a glossary containing key terms, a list of references, and an index of keywords that can be used to find information in the document.

REFERENCE

Federal Aviation Administration. (1996). *Human factors design guide for acquisition of commercial-off-the-shelf subsystems, non-developmental items, and developmental systems* (DOT/FAA/CT-96/01). Atlantic City International Airport, NJ: DOT/FAA Technical Center.

Appendix A

Revised Chapter 5 – Automation Guidelines

5.0 Automation

Definitions. Automation is the independent accomplishment of a function by a device or system that was formerly carried out by a human. [Source: NRC 1998; Parasuraman & Riley, 1997]

5.1 General

□ 5.1.1 **Minimum automation human factors requirements.** An automated system should

a. provide sufficient information to keep the user informed of its operating mode, intent, function, and output;

b. inform the user of automation failure or degradation;

c. inform the user if potentially unsafe modes are manually selected;

d. not interfere with manual task performance; and

e. allow for manual override. [Source: Veridian (AHCI), 1998; Billings, 1997]

■ 5.1.2 **User in command.** Automated systems shall prevent the removal of the user from the command role. [Source: Billings, 1997]

Discussion. The reasoning behind this rule is twofold. First, it is ultimately the user who is responsible for the task. Second, automation is subject to failure. Therefore, it is the user, not the automation who must be in control of the system with the automation playing a subservient role. [Source: Billings, 1997]

■ 5.1.3 **Automate only to improve performance.** Functions shall be automated only if they improve system performance without reducing human involvement, situation awareness, or human performance in carrying out the intended task. [Source: Billings, 1991]

Discussion. The introduction of automation is often intended to reduce workload and augment performance; however, this is not always the result. Automation can lead to: distraction from the primary task, increased workload, boredom, or complacency. Automation can also have psychosocial impacts, influencing job satisfaction or self worth. [Source: Bowers, Deaton, Oser, Prince & Kolb, 1995; Danaher, 1980; Edwards, 1976; Parasuraman, Molloy, Mouloua, & Hilburn, 1996; Wiener, 1989; Wiener & Curry, 1980]

- ▫ **5.1.4 Human-centered automation.** Automation should be used to support the user(s) where appropriate (human-centered automation), not implemented simply because the technology is available (technology-centered automation). [Source: Billings, 1997]

- ▪ **5.1.5 Enabling users to carry out tasks.** Automation shall help or enable the users to carry out their responsibilities and tasks safely, efficiently, and effectively. [Source: Billings, 1991]

  Discussion. Carrying out a task **effectively** means producing the desired result. Carrying out a task **efficiently** means that the desired result is produced with a minimum of waste (usually in relation to time).

- ▪ **5.1.6 Clear relationship with user tasks.** The relationships between display, control, decision aid, and information structure and user tasks and functions shall be clear to the user. [Source: Nuclear Regulatory Commission (NUREG-700), 1996; Nuclear Regulatory Commission (NUREG/CR-6105), 1994]

  Discussion. The user needs to be able to see clearly how the display or decision aid, and so on, facilitates the completion of the necessary task.

- ▪ **5.1.7 Active involvement in operation.** Users shall be given an active role through relevant and meaningful tasks in the operation of a system regardless of the level of automation being employed. [Source: AHCI, 1998; Billings, 1991]

  Discussion. User awareness of system state cannot be sustained passively. Active involvement is essential for operators to exercise their responsibilities and be able to respond to emergencies. Reducing active involvement may be detrimental to the user's understanding of important information, may lead to longer response times in case of emergencies, or, in the long term, may lead to loss of relevant knowledge or skills. [Source: Galster, Duley, Masalonis, & Parasuraman, 2001; Garland & Hopkin, 1994; Hopkin, 1988; Sarter & Woods, 1992 (as found in Scerbo, 1996); Wickens, 1992 (as found in Scerbo, 1996)]

- ▫ **5.1.8 Appropriate to user expertise.** Procedures employed in automation should be appropriate to the user' s level of expertise with the system. [Source: Defense Information Systems Agency (DISA), 1996]

  Example. Shortcuts such as function keys can be provided for the more experienced users, whereas novice users can still use standard procedures.

□ **5.1.9 Implementing automation.** How automation is implemented should be determined by the explicit goals of the system, not by comparison between automated and manual systems. [Source: Wiener & Curry, 1980]

Discussion. When automation is implemented, explicit goals of the system need to be kept in mind, thus, an automated system does not need to perform a task the same way as it was performed manually to be effective.

□ **5.1.10 Demands for cognitive resources.** Automation should not increase the demands for cognitive resources (thinking or conscious mental processes). [Source: Bainbridge, 1983; Parasuraman & Riley, 1997; Wiener & Curry, 1980; Woods, 1996]

Discussion. Automation that increases the demand for cognitive resources is considered clumsy. Expert users in complex, dynamic systems have been observed to cope with clumsy automation by using only a subset of the available functionality, especially during periods of high workload. [Source: Woods, 1996]

□ **5.1.11 Avoid extreme workload levels.** Extreme levels of workload (low or high) due to automation use should be avoided. [Source: Hilburn, Jorna, Byrne, & Parasuraman, 1996; NRC, 1993; Warm, Dember, & Hancock, 1996; Wiener, 1988]

Discussion. Extreme levels of workload can be caused by clumsy automation. Clumsy automation can cause extreme workload levels by increasing workloads when they are already high (e.g., for pilots, during the high workload flight phases of take-off and landing) and decreasing workloads that are already low (e.g., providing a pilot with the ability to engage autopilot during the low workload "cruise" phase of a flight). Automation is often introduced to reduce workload. However, reduction of workload may not always be advantageous, for example, if workload is already low. [Source: Hilburn et al., 1996; Parasuraman & Mouloua, 1996]

■ **5.1.12 Distraction from operations.** User interaction with automation shall not require the user to take significant amounts of attention away from the primary task. [Source: Danaher, 1980]

Discussion. When automation requires the user or one member of the user team to devote a significant amount of attention to adjusting or monitoring the automation, this removes the user away from minute-to-minute operations, thereby taking the user out of the loop. This can be especially dangerous if an abnormal situation occurs that needs to be remedied quickly. [Source: Danaher, 1980]

□ **5.1.13 Inappropriate timing.** Automation should not interrupt at inappropriate times such as during periods of high workload or during critical moments in a process. [Source: Woods, 1996]

Discussion. An interruption during high workload or at a critical moment can cause a delay in the user's ability to respond to a malfunction, leading to a potential failure. If the user is attending to a malfunction in an automated task and is interrupted, the interruption depletes the user's resources causing him to be less capable of averting the potential failure. For example, in the cockpit, certain automation functions might be stopped from interrupting during the takeoff and landing portions of flight.

□ **5.1.14 Easier to perform.** An automated task should be less difficult to perform than the manual task it replaces. [Source: AHCI, 1998]

□ **5.1.15 Guided use of automation.** Standard operating procedures and company policies should guide users in the appropriate use of automation, although the user should be ultimately responsible to make the decision to use or not use the automation. [Source: Billings, 1997; Parasuraman & Riley, 1997]

■ **5.1.16 Easy data access.** Data that are needed by the user shall be easily accessible. [Source: NUREG/CR-6105, 1994; NUREG-0700, 1996]

Discussion. User requirements can serve as a guide of whether the data are available at all times, accessible at the users' discretion, or not at all if the user does not need information.

□ **5.1.17 Data entry format.** The automated system should prompt users as to the correct data entry format. [Source: Billings, 1996]

Example. If the automated system requires that the data be entered in all capital letters, it should specifically tell the user to enter the data in capital letters.

□ **5.1.18 Error resistance and error tolerance.** Automation should be error resistant and error tolerant. [Source: Billings, 1991]

Discussion. To make a system **error resistant** is to make it difficult for a user to make an error. Simplicity in design and the provision of clear information are tools to improve error resistance. **Error tolerance** is the ability to mitigate the effects of human errors that are committed. Error tolerance can be improved by adding monitoring capabilities to the automation. Electronic checklists also have the potential to improve error resistance by providing reminders of items that need to be completed. [Source: Billings, 1991]

- **5.1.19 Predictable automated systems.** Automated systems shall behave predictably so that the user knows the purpose of the automation and how the operation will be affected by that automation. [Source: Billings, 1991, 1996]

  Discussion. The predictability of an automated system allows the user to know what to expect when the automation is functioning correctly. This makes it easier for the user to recognize when the system is not functioning. [Source: Billings, 1996]

- **5.1.20 Ensure safe operations are within human capacity.** Systems shall not be so reliant on automation or on human skills degraded by automation use that human users can no longer safely recover from emergencies or operate the system manually if the automation fails. [Source: Billings, 1996; NRC, 1998]

  Discussion. A balance is needed between the efficiency created by automation, the need for the operator to be able to recover from emergencies, and control the system manually in case the automation fails.

- **5.1.21 Veto of user actions.** The automation should not be able to veto user actions leaving the user without means to override or violate the rules that govern the automation unless there is not enough time for the user to make a decision. [Source: Garland & Hopkin, 1994; Inagaki, 1999]

  Discussion. Problems with automation can occur when the automated options do not apply to a situation and the user is restricted to the options provided by the automation.

- **5.1.22 Interaction consistency.** The way that automation systems interact with their users shall reflect a high degree of consistency within and between systems. [Source: NUREG-700, 1996]

  Discussion. There are many possible types of interaction, such as menu selection, direct manipulation, and form-filling. (See Revised Chapter 8 on computer-human interfaces for more information on interaction). An example of inconsistent interaction would be having one system require filling in forms as the interaction method, whereas another system requires menu-driven interaction.

- **5.1.23 Easy to understand and use.** Automated systems and associated integrated information displays should be intuitive, easy to understand, and easy to use. [Source: Billings, 1991; Sarter & Woods, 1994; Woods, 1996]

  Discussion. System operations that are easily interpretable or understandable by the user can facilitate the detection of improper operation and the diagnosis of malfunctions. [Source: Wiener & Curry, 1980]

- **5.1.24 Simple to learn.** Automation should be simple for the users to learn. [Source: Billings, 1991; Wiener & Curry, 1980]

- **5.1.25 Input and setup.** Automated systems should provide a way to check automation setup and to check information used as input for the automated system. [Source: Wiener & Curry, 1980; Wickens, 2000]

  Discussion. Automation failures are often due to setup error. Although the automated system itself could check some of the setup, independent error-checking equipment or procedures may be needed. The user needs to be able to distinguish whether a failure occurred due to the automation setup or due to an inaccuracy in the input information. An automation failure could have been caused by a malfunction of an algorithm or by the input of inaccurate data. For example, if the automated system relies on primary radar and secondary radar as inputs and uses an algorithm to predict conflicts, a failure could arise from faulty data from either the primary or secondary radar or from the algorithm that combines this information. [Source: Wiener & Curry, 1980; Wickens, 2000]

5.2 Design and evaluation

- **5.2.1 User involvement in design.** Users should be involved in the design of an automated tool. [Source: Amalberti, 1999; Billings, 1997; Parasuraman, Sheridan, & Wickens, 2000]

  Discussion. Input from the user is essential in defining information requirements.

- **5.2.2 Design based on human-centered goals and functions.** Design of automation should begin by choosing the human-centered criteria (goals) of the system and then defining the functions that the system will perform. [Source: Wiener & Curry, 1980]

  Discussion. Defining the goals and functions of an automated system may require the use of task analysis.

- **5.2.3 Effect on coordination.** When new automation is introduced, the designers shall consider the possibility of negative effects on team coordination. [Source: Wiener, 1989]

  Discussion. Automation may deplete team interaction and cooperation unless all parties are provided with information that allows them to be actively involved in the task. Automation can cause physical difficulty in seeing what the other team member is doing, reduce the ability to cross monitor, change traditional roles and responsibilities, and change the manner in which team members attempt to help one another. [Source: Danaher, 1980; Rudisill, 1994]

- **5.2.4 Assess overall impact.** The overall impact of automation shall be thoroughly examined before implementation to ensure that changes do not result in additional complexities, loss of situational awareness, or possibilities for error. [Source: Woods, 1996]

  Discussion. Automation of some user tasks may result in the user processing less information or processing information at less depth. A diminished understanding and appreciation for the overall situation may result. [Source: Garland & Hopkin, 1994]

- **5.2.5 Validation.** Contextually valid human-in-the-loop experiments and simulations should be conducted to validate and refine automated system design. [Source: NRC, 1998]

- **5.2.6 Interaction with other functions.** Possible interactions with other tools, system functions, and user tasks shall be evaluated when new automation is designed. [Source: NRC, 1998]

- **5.2.7 Integration.** New automation components shall be tested with the complete system, including other automated components of the system, to ensure they function together as an effective whole. [Source: NRC, 1998]

- **5.2.8 Testing in normal and failure modes.** Automated systems shall be tested under normal modes of operation and under failure modes of the automation. [Source: NRC, 1998; Wickens, 2000]

- **5.2.9 Test before implementation.** Automated systems shall be tested in a realistic operational environment with representative users before implementation to ensure that operator performance is not compromised and workload is not increased. [Source: Drury, 1998]

5.3 System response and feedback

- **5.3.1 Visualize consequences of decisions.** The user should be able to visualize the consequences of a decision, whether made by the user or the automated system. [Source: Billings, 1996]

- **5.3.2 Command response.** Automated system responses to user commands should be brief and unambiguous. [Source: Billings, 1997]

- **5.3.3 User awareness of function.** The automated system should keep the user aware on a continuing basis of the function (or malfunction) of each automated system and the results of that function (or malfunction). [Source: Billings, 1996]

- **5.3.4 Feedback.** Automation should provide the user with effective feedback on its actions and the purpose of these actions. [Source: Woods, 1996]

  Discussion. When feedback is poor, automation is considered silent. Silent automation may result in coordination and system failures. Users may be surprised by the behavior of silent automation. [Source: Woods, 1996]

5.4 Interface

- **5.4.1 Interface simplicity.** The automation interfaces should represent the simplest design consistent with functions and tasks of the users. [Source: NUREG-700, 1996]

  Discussion. Simplicity for the user is achieved by attaining compatibility between the design and human perceptual, physical, cognitive, and dynamic motor responsiveness capabilities. (See HFDG Update: Revision to Chapter 8 (Ahlstrom & Longo, 2001) on computer-human interfaces for more information on interface design.) [Source: NUREG-700, 1996]

- **5.4.2 Interface consistency.** Human interfaces in automation programs and systems shall have a high degree of consistency. [Source: NUREG-700, 1996]

  Discussion. Consistency can be obtained by presenting information in predictable locations and keeping elements of screens such as headers, fields, and labels consistent in appearance and relative location throughout a system or application. (See HFDG Update: Revision to Chapter 8 (Ahlstrom & Longo, 2001) on computer-human interfaces for more information on interface design.) [Source: Shneiderman, 1998]

- □ 5.4.3 **Consistent with user expectations.** Automated systems and interfaces should be consistent with the expectations and understandings of users. [Source: Billings, 1991, 1996]

- ■ 5.4.4 **Logical interface structure.** Automation interfaces shall reflect an obvious logic based on user task needs and capabilities. [Source: NUREG-6105, 1994; NUREG-700, 1996]

- ■ 5.4.5 **Location status.** Interfaces and navigation aids shall make it easy for users to know where they are in the data space. [Source: NUREG-6105, 1994; NUREG-700, 1996]

- □ 5.4.6 **Use spatial representations where possible.** Where possible, spatial representations of information should be used instead of verbal or textual displays in high workload situations. [Source: Barnes, 1981]

  Discussion. Although humans are often better able to attend to spatial representations, it is not always easy or even possible to create spatial representations of information. [Source: Barnes, 1981]

- □ 5.4.7 **Dynamic information.** Dynamic information (information that changes over time) should be presented in real time and on demand to ensure accurate and timely decision-making. [Source: Morris, Rouse, & Ward, 1985]

5.5 User acceptance and trust

- **5.5.1 User trust in automation.** To increase user trust in automation, automation performance should be

  a. reliable and predictable with minimal errors,

  b. robust (able to perform under a variety of circumstances),

  c. familiar (use terms and procedures familiar to the user), and

  d. useful. [Source: Lee & Moray, 1992; Lerch & Prietula, 1989; Masalonis & Parasuraman, 1999; Muir, 1987 (as found in Riley, 1996); NRC, 1998]

  Discussion. Trust in automation tends to be relatively stable. However, changes in trust may occur over time. User trust in automation can increase with reliable and predictable performance. Decreases in trust may occur as a result of some critical error or automation failure. It is more difficult for users to regain trust in automation after a failure than to develop an initial trust. Higher trust in automation is not always better because automation errors may be overlooked due to complacency. Decreases in trust typically occur suddenly, but increases happen slowly and steadily. The consequences of an automation failure (e.g., the magnitude of an error) impact the decline in trust. [Source: Lee & Moray, 1992; Lerch & Prietula, 1989; Masalonis & Parasuraman, 1999; Riley, 1996; NRC 1998]

- **5.5.2 Trust calibration.** Training should be provided to enable the user to calibrate their trust in the automated system. [Source: Cohen, Parasuraman, & Freeman, 1998]

  Discussion. Training will allow the user to develop an adequate model of how reliable or unreliable the automation is under specific conditions.

- **5.5.3 Availability of automation.** The automated system should be available to the user as needed. [Source: Morris, Rouse, & Ward, 1985]

- **5.5.4 Noninterference with user tasks.** The automated system shall not interfere with task performance. [Source: Andes, 1987]

  Discussion. A user will be less likely to accept an automated system that interferes with their ability to perform tasks. [Source: Andes, 1987]

- **5.5.5 Accurate and reliable information.** Automation shall provide accurate and reliable information. [Source: Andes, 1987]

  Discussion. When users believe automation to be highly reliable, they place greater trust in it. However, there is a trade-off involved with a constant high level of automation reliability and predictability. Constant high levels of automation reliability and predictability may be more likely to promote complacency and may cause users to monitor automation with less vigilance. [Source: Dzindolet, Pierce, Beck, & Dawe, 1999; Parasuraman, Molloy, & Singh, 1993, (as found in Masalonis & Parasuraman, 1999); Wiener, 1981]

- **5.5.6 Minimize changes due to automation.** Changes in cognitive processing, ways of thinking, and methods and skills used for new automation should be minimized. [Source: Garland & Hopkin, 1994]

  Discussion. Automation that requires different kinds of cognitive processing, ways of thinking, and discarding of traditional methods and skills may cause the system to be both less efficient and less acceptable to the users. This could include automatic conversion of data into a usable format. [Source: Garland & Hopkin, 1994]

- **5.5.7 Understanding of automation function.** To promote user acceptance of automation, users should be taught how an automated system functions. [Source: Cohen et al., 1998; Dzindolet et al., 1999; Lehner, Mullin, & Cohen, 1989]

  Discussion. The better the user understands the automation, the more likely the user is to trust the automation appropriately. Designers need to alter the false belief that automation is perfect and ensure that the users understand when the automation is likely to become unreliable. [Source: Dzindolet et al., 1999]

5.6 Modes

- **5.6.1 Clear mode and function identification.** When control, display, or automation functions change in different modes of operation, mode and function identification and status should be clear. [Source: Billings, 1991; Sarter & Woods, 1995]

  Discussion. Lack of effective feedback on the state of automation (including which mode is active) can lead to mode errors. [Source: Sarter & Woods, 1995]

- **5.6.2 Identification of alternatives in rarely used modes.** Seldom-used modes and functions should be clearly identified. [Source: Billings, 1991]

  Example. As automated systems become more complex with many modes and functions, the cognitive burden caused by the need for mode awareness increases. Seldom-used modes and functions will pose the largest burden on the user because of a lack of familiarity. Enabling the user to immediately recognize the purpose of modes and functions, such as labeling the engine failure function "ENG OUT", can lessen this burden. [Source: Billings, 1997]

- **5.6.3 Mode accessibility.** Frequently used modes should be more accessible than infrequently used modes. [Source: AHCI, 1998]

- **5.6.4 Number of modes.** The number of different modes for a given system should be minimized. [Source: AHCI, 1998]

  Discussion. Multiple modes will provide a means of flexibility but will introduce more opportunities for error. Furthermore, automation that has multiple modes of operation can be difficult to learn and can produce increases in workload. Users must understand and remember how and when to use each mode, and they must remember which mode is currently active. [Source: Scerbo, 1996; Woods, 1996]

- **5.6.5 Switching between modes.** The user should be able to easily switch between modes. [Source: AHCI, 1998]

- **5.6.6 Consistent features and functions.** Features and functions that are common between display modes should be consistent. [Source: AHCI, 1998]

  Discussion. In the original Standard Terminal Automation Replacement System (STARS), the Full Service Level (FSL) and the Emergency Service Level (ESL) had independent and inconsistent interfaces requiring users to learn two different interfaces: mouse interaction styles and status-coding schemes. This can lead to additional training requirements and workload. The human factors team recommended that the two subsystems have identical coding strategies, identical access and execution of system commands, consistent data display formatting, and consistent monitoring and reporting of resources. [Source: Standard Terminal Automation Replacement System Human Factors Team, 1997, 1998]

- **5.6.7 Interactions between modes.** The automated system should alert the user to the implications of interactions between modes, especially when they are potentially hazardous. [Source: Billings, 1996]

- □ 5.6.8 **Alert to unsafe modes.** The automated system should either prevent the use of potentially unsafe modes or alert the user that a particular mode may be hazardous. [Source: Billings, 1996]

5.7 Monitoring

- ■ 5.7.1 **Monitoring automated systems.** The system shall be designed so that users are able to monitor the automated systems and the functionality of its hardware and software, including the display of status and trend information, when necessary. [Source: Billings, 1991]

  Discussion. One way that this can be accomplished is by providing the user with access to raw data that the automation processes.

- ■ 5.7.2 **Monitoring changing data.** Changing data that must be monitored by the users should be displayed in a graphic format. [Source: Smith & Mosier, 1986]

- □ 5.7.3 **Active control and monitoring.** Automation should be designed so that users are involved in active control and monitoring rather than just passive monitors. [Source: Hilburn, Jorna, & Parasuraman, 1995; Wickens & Kessel, 1979]

  Discussion. Automation failures may be easier to detect when users are involved in both active control and monitoring, than when they are just passive monitors. [Source: Hilburn et al., 1995; Wickens & Kessel, 1979]

- □ 5.7.4 **Monitoring resources.** System designers should allow adequate cognitive resources for monitoring by ensuring that task load does not become excessive. [Source: Wiener & Curry, 1980]

  Discussion. Users of automated systems may experience higher levels of mental workload than manual controllers due to monitoring, diagnosis, and planning, with significant cognitive demand resulting from relatively "simple" vigilance tasks. [Source: Deaton & Parasuraman, 1993; Sheridan, 1970; Warm et al., 1996]

- □ 5.7.5 **Limited monitoring time.** Users should not be required to perform purely monitoring tasks for longer than 20 minutes at a time. [Source: Parasuraman et al., 1993; Warm et al., 1996]

  Discussion. Users may become complacent in monitoring automated systems if they have other tasks to complete simultaneously. Such decrements in user monitoring of automated systems have been observed to occur in the laboratory in as little as 20 minutes. [Source: Parasuraman et al., 1993; Warm et al., 1996]

- **5.7.6 Display integration.** When users must monitor multiple displays, important events should occur in the same display in order to promote effective monitoring performance. [Source: Warm et al., 1996]

- **5.7.7 Spatial certainty.** Important events should occur in the same location on a display in order to promote effective monitoring performance. [Source: Warm et al., 1996]

  Discussion. Users will be able to detect a particular event more easily if they know where that event will occur (i.e., spatial certainty). Spatial uncertainty has been shown to increase perceived workload and decrease performance efficiency. If users do not know where on a display an event will occur then they must engage in visual scanning to look for the event. [Source: Adams & Boulter, 1964; Milosevic, 1974 (as found in Warm et al., 1996)]

- **5.7.8 Indication of monitoring.** Automated systems that are without incident for long periods of time should provide some type of indication that the automation is still monitoring the system. [Source: AHCI, 1998]

- **5.7.9 Monitoring human interactions.** Automated systems should be able to monitor user interactions and to warn of user errors. [Source: Billings, 1991]

  Discussion. To monitor user interactions and to warn of user errors, automated systems may need to be able to receive input information on user intentions.

- **5.7.10 Monitoring of critical functions.** Critical automation functions should be independently monitored by the user. [Source: Billings, 1996]

  Definition. A **critical function** is a function that can cause system failure when a malfunction is not attended to immediately.

  Discussion. When a function is critical, combining the monitoring of that critical function with other, possibly less critical functions may lead to delays in response. When a critical function is independently monitored, a user can respond to a malfunction very quickly (within one second). If a user is attending to another task when there is a malfunction, there will be a delay in the user's response (several seconds). In this period of delayed response, the malfunction can cause the system to fail. For this reason, critical functions require constant attention. Critical automation functions do assist in the completion of critical tasks, however they do not assist in freeing the user to attend to other tasks. [Source: Parasuraman et al., 1996]

▫ **5.7.11 Adequate mental model.** Users should be given an adequate understanding of how the automated system works in order to monitor effectively. [Source: Carroll & Olsen, 1988 (as found in Scerbo, 1996); Wickens, 1992 (as found in Scerbo, 1996); Wickens & Flach, 1988; Woods, 1994 (as found in Scerbo, 1996); Woods, 1996]

Discussion. Users must possess accurate mental models of automated systems in order to monitor effectively, comprehend current situations, plan their actions, predict future system states, remember past instructions, and diagnose system failures. One way to establish adequate mental models is through training. [Source: Scerbo, 1996; Wickens, 1992 (as found in Scerbo, 1996); Wickens & Flach, 1988; Woods, 1994 (as found in Scerbo, 1996); Woods, 1996]

▫ **5.7.12 Intermittent manual control.** Intermittent periods of manual control should be used during extended periods of task automation to improve monitoring of the automation. (See adaptive automation section 5.13.) [Source: Morrison, Cohen, & Gluckman, 1993; Parasuraman et al., 1993]

Discussion. Complacency is a major concern with automation. Intermittent periods of manual control have been advocated as a means of minimizing complacency. Automation may also result in the decrement of cognitive abilities such as instrument scan and navigation/positional [situation] awareness and the loss of manual skills, making transitions from automated to conventional systems difficult. Because automation can decrease basic manual skills, these skills should be used and maintained. Intermittent periods of manual control during which automation is suspended periodically can promote optimal user performance, and allow better recovery from failure, regardless of the type of task that is automated. [Source: Endsley & Kiris, 1995; Morrison et al., 1993; Rudisill, 1994; Wickens, 1992 (as found in Scerbo, 1996)]

▫ **5.7.13 Minimize noise.** Environmental noise should be minimized to ensure optimal vigilance. [Source: Warm et al., 1996]

Discussion. Vigilance will be reduced when high levels of intermittent noise are present in the environment, especially if the information processing task demands are high. Noise is defined as sounds that are loud, disagreeable or unwanted. Music, however, may act as a stimulant and offset decrements in arousal due to fatigue and prolonged performance. [Source: Davies, Lang & Shackleton, 1973; Hancock, 1984 (as found in Warm et al., 1996); Matthews, Davies, Westerman, & Stammers, 2000]

□ **5.7.14 Circadian rhythm effects on performance.** System designers should consider the effects of circadian rhythms on user vigilance and monitoring performance. [Source: Colquhoun, 1977 (as found in Warm et al., 1996)]

Discussion. It will be most difficult for users to maintain monitoring performance during the early morning (8:00 a.m.) when body temperature is low. Performance will peak late in the day (between 5:00 p.m. and 9:00 p.m.) as body temperature rises. Monitoring performance will then decline again as body temperature drops. Maintaining monitoring performance can also be difficult for users working irregular work schedules. Working consecutive night shifts, prolonged work shifts, or starting hours that are too early can cause users to experience a desynchronization of their circadian rhythm caused by the accumulation of sleep deficit and fatigue. [Source: Costa, 1999; Warm et al., 1996]

□ **5.7.15 Vigilance decrement.** The effects on vigilance due to the use of automation should be considered before introducing new automation. [Source: Warm et al., 1996]

Discussion. A **vigilance decrement**, that is, a continuously decreasing ability to maintain attention over time while monitoring, may occur with the use of automation.

Vigilance decrements do not occur because monitoring tasks are under stimulating. Rather, they require a large amount of cognitive resources and are often frustrating. Vigilance decrements have been observed to occur for both expert and novice users in high fidelity simulations and real-world operations. [Source: Baker, 1962; Colquhoun, 1967, 1977; Mackworth, 1948, 1961; Schmidke, 1976 (as found in Warm et al., 1996); Warm et al., 1996]

How hard the user must work in order to maintain vigilance can be determined by at least two factors. First, workload is affected by the ease with which relevant signals can be detected. Signals that have low salience are more difficult to detect than signals high in salience. Visual fatigue will also require more effort to be expended in order to detect a signal. Second, musculo-skeletal fatigue associated with maintaining a fixed posture will increase the workload needed to perform optimal monitoring. [Source: Dember, Warm, Nelson, Simons, Hancock, & Gluckman, 1993, Warm et al., 1996]

5.8 Fault management

Fault management relates to how the user notices and recovers from system failures. Such failures may or may not be detected by automation. Fault management has been defined to include the four distinct tasks of detection, diagnosis, prognosis, and compensation. [Source: Rogers, Schutte, & Latorella, 1996]

■ 5.8.1 **Failure recovery.** Automated systems shall allow for manual control and preservation of safe operations should the automation or one or more components of the system, on which the automation depends, fail. [Source: NRC, 1998]

Discussion. The resumption of manual control needs to be within the capacity of the user, without relying on manual skills that may be degraded by the use of automation. [Source: NRC, 1998]

■ 5.8.2 **Failures made apparent.** Automation failures shall be made unambiguously obvious to the user. [Source: AHCI, 1998; Billings, 1991]

Discussion. Stress, preoccupation, and distraction may reduce the user's ability to detect faults. [Source: Rogers et al., 1996]

□ 5.8.3 **Early warning notification.** Early warning notification of pending automation failure or performance decrements should use estimates of the time needed for the user to adjust to task load changes due to automation failure. [Source: Morrison, Gluckman, & Deaton, 1990]

Discussion. In situations where automation failure would require user intervention, it is useful for the user to be warned that he will need to take manual control before the automated system fails. Ideally, this warning needs to come in adequate time to allow the user to adjust to the new task load. There may, however, be cases where it is not possible to provide advance notification of pending failure or where the estimate of time needed for the user to take control is unknown. [Source: Morrison et al., 1990]

■ 5.8.4 **Informing user of potential failure.** The user shall be informed of automation performance decrements, potential failures, and malfunctions. [Source: Billings, 1996]

Discussion. It can increase workload for the user to continually monitor the automation for failure. Advance knowledge about potential failures can also help the user prepare to take manual control.

■ 5.8.5 **Automated diagnostic aids.** Fault isolation, inspection, and checkout tasks shall be automated to the extent practical. [Source: National Air Space Administration (NASA-STD-3000A), 1989]

- **5.8.6 Automatic self-checking components.** All essential electronic computer and peripheral components that are part of a system shall incorporate an automatic self-check diagnostic test of software and hardware, both at power up and at the request of the operator, to ensure they are functioning properly. [Source: Department of Defense, (DoD MIL-STD-1472D), 1981]

- **5.8.7 On-demand system check.** On-demand system checkout shall be available. [Source: NASA-STD-3000A, 1989]

- **5.8.8 Sensor verification.** The status of sensors on replacement units shall be verifiable with respect to accuracy and proper operation. [Source: NASA-STD-3000A, 1989]

- **5.8.9 Equipment verification.** When feasible, equipment shall permit verification of operational status prior to installation without the need for disassembly. [Source: NASA-STD-3000A, 1989]

- **5.8.10 Fault detection without disassembly.** Equipment shall permit fault detection and isolation without removing components, through the use of built-in test, integrated diagnostics, or standard test equipment. [Source: Department of Defense (MIL-STD-1800A), 1990; NASA-STD-3000A, 1989]

- **5.8.11 Rapid fault detection.** Equipment design shall facilitate rapid fault detection and isolation of defective items to permit their prompt removal and replacement. [Source: DoD MIL-STD-1472D, 1981; NASA-STD-3000A, 1989]

- **5.8.12 Fault detection without ambiguity.** Fault detection and isolation shall identify without ambiguity which component has failed. [Source: DoD MIL-STD-1800A, 1990; NASA-STD-3000A, 1989]

- **5.8.13 Portable diagnostic tools.** When built-in test equipment is not available, diagnostic tools or portable equipment shall be provided to aid in fault isolation. [Source: NASA-STD-3000A, 1989]

- □ **5.8.14 First-event processing.** Automated warning systems should provide a means for identifying the first event in a series of alarm events. [Source: NUREG-0700, 1996]

  Discussion. When a series of interrelated alarms occur, information identifying which component first exceeded the set threshold can be valuable in determining the initiating cause of a problem. [Source: NUREG-0700, 1996]

□ 5.8.15 **Diagnostic information.** The user should be provided with sufficient information and controls to diagnose automated warning system operation. [Source: Wiener & Curry, 1980]

Discussion. In order for the user to diagnose the automated system, diagnostics information needs to be self-explanatory and in plain English. The diagnostic information must provide the user with the information they need without requiring the user to seek additional references, or a help function, to understand the problem and the recommended solution.

5.9 False alarms

□ 5.9.1 **False alarm rates.** False alarm rates should not be so frequent as to cause the user to mistrust the automated system. [Source: NUREG/CR-6105, 1994; Parasuraman, Hancock, & Olofinboba, 1997; Wiener & Curry, 1980]

Discussion. The trade-off between alerting the user to off-normal conditions and the creation of nuisance alarms needs to be considered when determining appropriate alarm set points. A system that is designed to minimize misses, at all costs, is likely to have frequent false alarms. However, automated systems that have frequent false alarms are unlikely to be trusted or even tolerated. When there is low probability that the alarm is a true alarm (the "cry-wolf" phenomenon), users tend to ignore, mistrust or turn off alarms. Setting the false alarm threshold requires careful evaluation of the trade offs between missed signals and false alarms including not only the decision thresholds at which the system is set, but also the probabilities of the condition to be detected. [Source: NRC, 1997]

□ 5.9.2 **Inform users of the probability of a true alarm.** Users should be informed of the inevitable occurrence of automation false alarms particularly when base rates are low. [Source: NRC, 1998]

Discussion. When the probability of an event is low, the odds of a true alarm can be quite low for even a very sensitive warning system, causing inevitable false alarms. [Source: NRC, 1998; Parasuraman et al., 1997]

5.10 Training

- **5.10.1 Introducing new automation.** New automation should be introduced with advanced briefing and subsequent training procedures. [Source: Billings, 1997; NRC, 1998; Parasuraman & Riley, 1997]

    Discussion. The introduction of new automation may introduce changes in traditional roles and responsibilities, a redistribution of authority for tasks or changes to the nature of the cognitive demands imposed on the human operator. [Source: Bowers et al., 1995; Wiener, 1989]

- **5.10.2 Prepare users for changes.** Before automation is introduced, users should be informed of associated changes and increases in the work effort, as well as the benefits associated with the automation. [Source: DISA, 1996; Scerbo, 1996]

    Discussion. The roles and responsibilities of the users, cognitive demands, and operational procedures may change as a result of introducing automation. [Source: Bowers, Deaton, Oser, Prince, & Kolb, 1995]

- **5.10.3 Understanding automated functions.** Initial training in the use of automation should be sufficient for the users to fully understand how the automation functions within the particular system, as well as how to use the automation. [Source: Billings, 1997]

    Discussion. Lack of knowledge and understanding of how automation works can make it difficult for users to assess potential problems and may result in improper use of automation. [Source: Rudisill, 1995]

- **5.10.4 Backup training.** Users should be provided with backup training in performing any tasks replaced by automation or in operating any backup systems replaced by automation. [Source: DISA, 1996]

□ **5.10.5 Inappropriate use of automation.** Users should be trained to recognize inappropriate uses of an automated tool including automation bias (the use of automation in a heuristic manner as opposed to actively seeking and processing information). [Source: DISA, 1996; Dzindolet, Pierce, Beck, & Dawe, 1999; Mosier & Skitka, 1999]

Discussion. There are different categories of inappropriate automation use, including automation bias, ignoring or turning off the automation, and improper implementation of automation.

Users may rely on automated decision aids in a heuristic manner (referred to as **automation bias**). Using heuristics is to apply simple decision-making rules to make inferences or to draw conclusions simply and quickly. Heuristics are useful principles having wide application, but may not be strictly accurate. Usually a heuristic strategy is optimal, however, under certain conditions heuristics will be inappropriate and errors or misuse may occur. Automation bias leads to errors of omission (failure to notice system anomalies when automation fails) and errors of commission (acceptance of automated decisions without cross-checking or in presence of contradictory information). Training will help prevent automation bias and help the user learn to examine multiple sources of information before making a decision. Early training on automation bias may reduce commission errors for users new to automation, but may be less likely to reduce omission errors or errors made by expert users.

Inappropriate use of automation may be influenced by various individual factors such as self-confidence in completing the task, trust in the automation, differential effects of fatigue, and how all of these factors combined weigh into the decision making process. Inappropriate use of automation can be due to misuse (automation bias, complacency), disuse (ignoring or turning off automation) or abuse (improper implementation of automation). [Source: Dzindolet et al., 1999; Lee & Moray, 1992; Mosier & Skitka, 1996; Mosier, Skitka, Dunbar, Burdick, McDonnell, & Rosenblatt, 1998; Muir, 1987 (as found in Scerbo, 1996); Parasuraman & Riley, 1997; Riley, 1996]

- **5.10.6 Automation reliability training.** Users should be trained to recognize and understand the conditions under which automation may be unreliable, and to learn the conditions where it performs well (when or when not to question the automation). [Source: Cohen et al., 1998; Dzindolet et al., 1999]

  Discussion. Users must learn not to categorically accept the recommendation of a decision aid. Understanding the automation's weaknesses allows users to better judge how much they should trust the automation without becoming overconfident in its performance. This recognition process may impose an additional workload on the user. [Source: Dzindolet et al., 1999]

- **5.10.7 Over-reliance on automation.** Users should be trained not to become overly reliant on automation. [Source: Mosier, Skitka, Heers, & Burdick, 1997; Parasuraman & Riley, 1997]

  Discussion. When users rely on automation too much they become susceptible to automation-induced complacency. Monitoring failures are likely to occur when users become overly reliant on automation. [Source: Mosier et al., 1994; Parasuraman et al., 1993]

- **5.10.8 Risk assessment and reduction.** Users should be trained on risk assessment and actions needed for risk reduction. [Source: Mosier & Skitka, 1999]

- **5.10.9 Transition training.** Users should be trained on transitioning from automated to conventional systems. [Source: Rudisill, 1994]

  Discussion. If automation were to fail, users need to be skilled at both recognizing the failure and taking manual control.

- **5.10.10 User-automation interaction.** Training programs should stress user-automation interaction skills and cognitive/problem solving skills rather than psychomotor skills. [Source: Sarter & Woods, 1994]

  Discussion. Problems in automation may not be inherent in the technology itself. Problems can arise due to limitations in the integration of the user and automation. The user and automation should be integrated by developing a joint, distributed cognitive system by means of training and design. [Source: Sarter & Woods, 1994]

- **5.10.11 Training for changes due to automation.** When automation requires different kinds of cognitive processing, ways of thinking, and discarding of traditional methods and skills, then training should be designed to address problems related to these changes. [Source: Garland & Hopkin, 1994]

□ **5.10.12 Automation output.** Users should be trained on what constitutes the normal automation output so that the user can easily determine whether the system is functioning properly. [Source: Morris et al., 1985]

5.11 Function allocation/levels of automation

There are many possible levels of automation (see Table 1) including: automation that automatically executes tasks, automation that performs tasks when pre-specified conditions are met, and automation that suggest a course of action or facilitates a decision. [Source: Billings, 1997; NRC, 1998; Parasuraman et al., 2000]

Table 1. Levels of automation, from high to low. [Source: NRC, 1998; Sheridan, 1996]

The system acts autonomously without human intervention
The system informs the user after executing the action only if the system decides it is necessary
The system informs the user after executing the action only upon user request
The system executes an action and then informs the user
The system allows the user a limited time to veto before executing an action
The system executes an action upon user approval
The system suggests one alternative
The system narrows the selection down to a few
The system offers a complete set of action alternatives
The system offers no assistance

□ **5.11.1 Function allocation alternatives.** Alternative function allocations including fully manual, partially automated, fully automated, and adaptive allocation should be evaluated for feasibility and effectiveness. [Source: Wiener & Curry, 1980]

□ **5.11.2 Evaluated through simulation.** Alternative schemes for the allocation of functions should be examined in the context of the whole system through the use of high fidelity simulations. [Source: Wiener & Curry, 1980]

Discussion. Because there may be multiple potential schemes in the allocation of functions, simulating these schemes in the context of the whole system will allow them to be evaluated properly. A scheme that seems to be the most appropriate in regards to accomplishing a specific task may not be the best choice in relation to the functioning of the entire automated system.

□ **5.11.4 Functions to automate.** Only functions that are performed well by machines should be automated, not functions that are performed better by humans. [Source: Drury, 1998]

- **5.11.5 Automate full behavioral modules.** Behavioral modules in their entirety should either be automated or preserved as manual subtasks, not fractionally (partially) automated. [Source: Vortac, Barile, Albright, Truitt, Manning, & Bain, 1996]

  Discussion. A behavioral module is a unitized set of actions that can be performed in an over-learned, automatic fashion with very little effort. When a set of cognitive or behavioral actions is frequently performed together they will eventually form a module. Automation that replaces only a portion of a module will produce no advantage in performance and may inhibit performance. [Source: Vortac et al., 1996]

- **5.11.6 User tasks.** Tasks that are performed in an unpredictable environment requiring flexibility and adaptability should be allocated to the user. [Source: AHCI, 1998]

- **5.11.7 Clear roles and responsibilities.** The automated system should make it clear whether the user or computer is supposed to perform a particular task at a specific time. [Source: Parasuraman & Riley, 1997]

- **5.11.8 Changing roles and responsibilities.** The automated system should provide a means for changing the allocation of roles and responsibilities. [Source: Parasuraman & Riley, 1997]

- **5.11.9 Automation of high-risk actions or decisions.** For system tasks associated with greater uncertainty and risk, automation should not proceed beyond the level of suggesting a preferred decision/action alternative. [Source: NRC, 1998]

  Discussion. High levels of automation can be used for tasks involving relatively little uncertainty and risk. [Source: NRC, 1998]

5.12 Information automation

Information automation includes information acquisition and integration. This type of automation would include filtering, distributing or transforming data, providing confidence estimates and integrity checks, and enabling user requests.

- **5.12.1 Incomplete, missing, uncertain, and invalid data.** The automated system should provide a means to indicate to the user that data are missing, incomplete, unreliable, or invalid or that the system is relying on backup data. [Source: AHCI, 1998]

- **5.12.2 Automatic update.** When the displayed data are changed as a result of external events, the user should be provided with the option of having an automatic update of changed information. [Source: AHCI, 1998]

□ 5.12.3 **Multiple formats.** System designers should provide information in multiple formats (e.g., text, graphics, voice, and video) to allow better communication and reduction of workload. [Source: Scerbo, 1996]

Discussion. Communication will be improved by allowing information to be presented in the most understandable format. Eliminating the need to translate information into a specific format will reduce workload. [Source: Scerbo, 1996]

□ 5.12.4 **Accurate reflection of status.** Information presented to the user should accurately reflect system and environment status in a manner so that the user rapidly recognizes, easily understands, and easily projects system outcomes in relation to system and user goals. [Source: Endsley & Kiris, 1995; NUREG-700, 1996]

□ 5.12.5 **Error Mitigation.** Error-prone conditions should be minimized by maintaining user awareness, providing adequate training, developing standard operating procedures, and fostering crew coordination. [Source: Sheehan, 1995]

Discussion. Errors due to automation may arise from data entry errors, monitoring failures, system workarounds, and mode misapplication. Error-prone conditions in automated systems may result from lack of mode awareness, lack of situation awareness, lack of systems awareness, increased heads down time, over-dependence on automation, and interrupted crew coordination. Automation-related errors usually occur in conjunction with other factors such as haste, inattention, fatigue, distraction, or other system factors. [Source: Sheehan, 1995]

■ 5.12.6 **Information display.** Information displays shall support and reinforce status and situation awareness at all times. [Source: Billings, 1991, 1996]

Discussion. A primary objective of information automation is to maintain and enhance situation awareness. However, too much information presented simultaneously may become cluttered and make visual search difficult, interfering with status, decision-making, or control. It is important for the user to be able to easily locate needed information. [Source: Billings, 1991]

The user's ability to detect a signal while monitoring varies inversely with the rate at which neutral background events are repeated. [Source: Lanzetta, Dember, Warm, & Berch, 1987; Parasuraman, 1979 (as found in Warm et al., 1996)]

■ 5.12.7 **Situation displays.** Event data should be combined with a map background when the geographic location of changing events needs to be shown. [Source: Smith & Mosier, 1986]

- 5.12.8 **Information presentation.** Both the content of the information made available through automation and the ways in which it is presented shall be consistent with the task priorities. [Source: Billings, 1996]

- 5.12.9 **Cueing important information.** When information must be updated quickly, the most important information should be cued to ensure it will be the first to be processed by the user. [Source: Wickens, 2000]

  Discussion. It is important that the cues be correct, as there may be significant costs of invalid cueing. [Source: Wickens, 2000]

- 5.12.10 **Automatic information queuing.** Incoming messages should be queued automatically by the system so they do not disrupt current information handling tasks. [Source: Smith & Mosier, 1986]

- 5.12.11 **Highlighting changed data.** Data changes that occur following automatic display update should be temporarily highlighted. [Source: Smith & Mosier, 1986]

- 5.12.12 **Lists of information.** Long lists of information, tasks, and so on, should be stored and prioritized by the automated aid to minimize the number of decision alternatives and reduce the visual processing load of human operators. [Source: Barnes, 1981]

- 5.12.13 **Integration of display elements.** Display elements should only be integrated if it will enhance status interpretation, decision-making, situation awareness, or other aspects of task performance. [Source: Billings, 1991]

- 5.12.14 **Integrated displays.** Integrated displays should combine various information automated system elements into a single representation. [Source: Billings, 1996; Parasuraman et al., 2000]

  Discussion. Feedback information that is widely distributed among various indicators can result in insufficient monitoring of automation and/or mode confusion. In such cases, monitoring adequacy is limited by inefficient scanning patterns and information that is difficult to integrate. [Source: Mosier & Skitka, 1999]

▫ **5.12.15 Integrated or non-integrated information arrangement.** System information should be automatically reorganized into integrated or non-integrated arrangements depending on the current system status. [Source: Forester, 1987; Parasuraman, et al., 1996]

Discussion. Integrated information arrangement allows the user to assess the overall status of the system. Integrating display components into aggregated arrangements may reduce the attention demands of fault detection. Non-integrated arrangement of components draws user attention to system errors or other relevant information. Presenting the information in a format relevant to the state of the system can facilitate the ability of the user to quickly and easily assess the system status. [Source: Forester, 1987; Parasuraman et al., 1996]

▫ **5.12.16 Equally prominent cues.** Automated and non-automated cues should be made equally prominent to enable users to collect confirming/disconfirming evidence before deciding on appropriate action. [Source: Mosier & Skitka, 1999]

Discussion. Automation bias, the tendency to use automation in a heuristic manner, may be suppressed if other, non-automated sources of information are presented with salience equal to that of the automated information. [Source: Mosier & Skitka, 1999]

5.13 Adaptive automation

Adaptive automation is the real time allocation of tasks to the user or automated system in a flexible manner, changing the automation to meet current situational demands. Adaptive automation may benefit user performance by allowing the user to remain in active control of the system instead of becoming a passive observer. Active control may prevent performance decrements associated with long-term monitoring, loss of situation awareness and manual skill degradation. [Source: Morrison et al., 1990; NRC, 1998; Scerbo, 1996; Scerbo & Mouloua, 1999]

Discussion. Laboratory experiments have shown that short periods of automation use (e.g., 10-minute cycles of manual and automated control) do not result in performance decrements. This suggests that intermittent periods of manual control may help to maintain performance in the presence of automation. [Source: Gluckman, Carmody, Morrison, Hitchcock, & Warm, 1993 (as found in Scerbo, 1996); Parasuraman et al., 1991]

- **5.13.1 Help during high workload.** Automation should be designed to adapt by providing the most help during times of highest user workload, and somewhat less help during times of lowest workload. [Source: Billings, 1996; Parasuraman, Mouloua, & Hilburn, 1998]

  Discussion. Research has shown that adaptive automation may reduce mental workload most effectively during periods of high taskload. [Source: Hilburn et al., 1996]

- **5.13.2 Adaptive automation timing.** Adaptive automation should not be implemented unexpectedly or at a time when the user may not desire the aiding. [Source: Scerbo, 1996]

  Discussion. The timing of adaptation may have critical impact on user acceptance of automation. Studies show that users prefer to be in control of the system. However, there are times that automation may need to be initiated by the system, particularly when changes in workload occur rapidly or are unexpected by the user. [Source: Harris, Goernert, Hancock, & Arthur, 1994 (as found in Scerbo, 1996)]

- **5.13.3 Adaptive automation implementation.** Adaptive automation should be implemented at the point at which the user ignores a critical amount of information. [Source: Sen, 1984]

  Discussion. Fatigue (or other factors) may prevent users from recognizing the best time to utilize automation and performance decrements may consequently occur. One indication that the user is being overloaded is an increase in the amount of information he must ignore in order to make a timely decision. Thus, the designer can use a threshold critical amount of ignored information as an indicator that the user is overloaded and implement adaptive automation at that point (to help reduce workload). What constitutes a critical amount of information can vary depending on the particular task and may best be determined on a system-by-system basis. [Source: Harris, Hancock, & Arthur, 1993 (as found in Scerbo, 1996); Sen, 1984]

- **5.13.4 Adapting to skill of the user.** Adaptive automation should be used to increase the performance of users with different skill levels. [Source: Norico & Stanley, 1989]

  Discussion. By adapting to the skill of the user, adaptive automation can increase the proficiency of the novice user and prevent frustration that might otherwise occur with complex systems.

- **5.13.5 Skill of adaptive automation.** Adaptive automation should be at least as skilled as the user, if not greater, to promote optimal user performance. [Source: Woods, 1996]

- **5.13.6 Modeling of human behavior.** Modeling of human behavior for aid-initiated intervention should at least include: task execution goal states, environment representation (graphical), situation assessment information and planning, and commitment logic. [Source: Andes & Hunt, 1989]

  Discussion. When modeling user behavior, it ought to be noted that users vary greatly in the way they employ automation. [Source: Lee, 1992; Lee & Moray, 1992 (as found in Riley, 1996)]

- **5.13.7 Interface adaptation.** When dynamic adaptation of the interface is used, it should be attained by utilizing information provided to the system through user interactions within a specific context. [Source: Norico & Stanley, 1989]

  Discussion. Dynamic adaptation of the interface may promote operator acceptance of automation.

- **5.13.8 Menu adaptation.** When dynamic adaptation of menus is used, the resultant menus should offer only the options that are relevant to the current environment. [Source: Barnes, 1985]

  Discussion. Dynamic adaptation of the menus occurs when menus are altered to reflect the needs of the current environment. This approach may reduce user workload. [Source: Barnes, 1985]

- **5.13.9 Direct manipulation interface.** Direct manipulation interfaces should be used to minimize the impact of a transition to manual control. [Source: Morrison et al., 1993]

  Discussion. An example of direct manipulation is a graphical user interface (GUI). In direct manipulation, the user controls the interaction with the computer by acting directly on objects on the display screen. An object may be an icon, menu option, symbol, button, or dialog box. (See HFDG Update: A Revision to Chapter 8 (Ahlstrom & Longo, 2001) on computer-human interfaces for more information on direct manipulation.) [Source: Shneiderman, 1992]

5.14 Decision aids

Definition. Decision aids (sometimes referred to as decision support systems) are automated systems that provide support to human decision-making processes either unsolicited or by user request. Decision aids can narrow the decision alternatives to a few or suggest a preferred decision based on available data. [Source: Wiener, 1988]

□ **5.14.1 Use.** Decision aids should be used

a. for managing system complexity;

b. for assisting users in coping with information overload;

c. for focusing the user's attention;

d. for assisting the user in accomplishing time-consuming activities more quickly;

e. when limited data results in uncertainty;

f. for overcoming human limitations that are associated with uncertainty, the emotional components of decision-making, finite-memory capacity, and systematic and cognitive biases; and

g. for assisting the user in retrieving, retaining, representing or manipulating large amounts of information, combining multiple cues or criteria, allocating resources, managing detailed information, performing computations, and selecting and deciding among alternatives. [Source: AHCI, 1998; DISA, 1996]

□ **5.14.2 When to avoid.** Decision aids should not be used

a. when solutions are obvious;

b. when one alternative clearly dominates all other options;

c. when there is insufficient time to act upon a decision;

d. when the user is not authorized to make decisions; or

e. for cognitive tasks in which humans excel, including generalization and adapting to novel situations. [Source: AHCI, 1998]

□ **5.14.3 User determination of decision aid use.** Users should be able to determine when and how the decision aid should be used. [Source: Parasuraman & Riley, 1997]

- **5.14.4 Appropriate to user.** Decision aids should use terminology and criteria appropriate to the target user group. [Source: DISA, 1996]

- **5.14.5 Reduce number of response options.** Decision aids should reduce the number of response options. [Source: Barnes, 1985]

  Discussion. The number of options that the user must consider is expected to decrease when a decision aid is used. Reducing the response options focuses the user's attention onto the most viable options.

- **5.14.6 Assist user decisions.** Decision aids should assist, rather than replace, human decision makers by providing data for making judgments rather than commands that the user must execute. [Source: AHCI, 1998; DISA, 1996; Parasuraman & Riley, 1997]

- **5.14.7 Consistent with mental models.** The support provided by decision aids should be consistent with user cognitive strategies and expectations (mental models). [Source: NUREG-700, 1996]

  Definition. A **mental model** is an individual's understanding of the processes underlying system operation. [Source: NRC, 1998; Parasuraman et al., 1996]

- **5.14.8 Non-cancellation of ongoing tasks.** Use of decision aids should not require on-going user tasks to be cancelled. [Source: NUREG-700, 1996]

- **5.14.9 Minimize query of user.** Decision aids should minimize query of the users for information. [Source: NUREG-0700, 1996]

- **5.14.10 Minimize data entry.** Decision aids should minimize user data entry requirements. [Source: DISA, 1996]

- **5.14.11 Planning strategy or guiding process.** Decision aids should be capable of planning a strategy to address a problem or guide a complex process. [Source: NUREG-0700, 1996]

- **5.14.12 Accept user direction.** Decision aids should accept direction from the users on which problem solving strategy to employ when alternative strategies are available. [Source: NUREG-0700, 1996]

- **5.14.13 Prioritize alternatives.** When more than one alternative is available, the decision aid should provide the alternatives in a recommended prioritization scheme based on mission and task analysis. [Source: AHCI, 1998]

- **5.14.14 Unable to process.** Decision aids should alert the user when a problem or situation is beyond its capability. [Source: NUREG-0700, 1996]

- **5.14.15 Type and sequence of input.** Decision aids should be flexible in the types and sequencing of user inputs accepted. [Source: NUREG-0700, 1996]

- **5.14.16 Uncertainty estimate and rationale.** Decision aids should estimate and indicate the certainty of analysis and provide the rationale for the estimate. [Source: NUREG-0700, 1996]

- **5.14.17 Derived or processed data.** When information used by a decision aid is derived or processed, the data from which it is derived should be either visible or accessible for verification. [Source: Billings, 1996]

  Discussion. Data that are not critical for operation can be made available only upon request.

- **5.14.18 Hard copy of decision aid use.** The user should be able to obtain hard copy print outs of data including screen displays, rules and facts, data employed, hypotheses tested, and summary information. [Source: NUREG-0700, 1996]

- **5.14.19 Access to procedural information.** Decision aids should give the user access to procedural information used by the aid. [Source: Morris, Rouse & Ward, 1985; NUREG-0700, 1996]

  Discussion. Procedural information is information about the rules or algorithms used by the decision aid. Knowledge of procedural information fosters user acceptance of the aid because the user is able to understand how the aid functions. As the user becomes more familiar with a given situation, he requires less procedural information. [Source: Morris et al., 1985]

- **5.14.20 Explanation detail.** When the system provides explanations to the user, it should supply a short explanation initially, with the ability to make available more detail at the user's request, including access to process information or an explanation for the rules, knowledge-basis, and solutions used by the decision aid. [Source: DISA, 1996; NUREG-0700, 1996]

  Discussion. Process information is the information about how the aid accomplishes a task. This information is required by users to decide whether to use the aid in unfamiliar situations and for identifying the nature and extent of malfunctions. [Source: Morris et al., 1985]

- **5.14.21 Clear explanations to user.** When the system provides explanations to the user, the explanation should use terms familiar to the user and maintain consistency with the immediate task. [Source: DISA, 1996]

- **5.14.22 Information presentation.** Decision aids should present information at the level of detail that is appropriate to the immediate task, with no more information than is essential. [Source: AHCI, 1998]

- **5.14.23 Avoid repeated information.** Decision aids should avoid repeating information that is already available. [Source: AHCI, 1998]

- **5.14.24 Decision aid integration.** Decision aids should be fully integrated and consistent with the rest of the computer-human interface. [Source: NUREG-0700, 1996]

- **5.14.25 Alert to newly available information.** Decision aids should alert the user to changes in the status of important system information such as when critical information becomes available during decision aid utilization. [Source: NUREG-0700, 1996]

  Discussion. Critical information in this guideline refers to information that may have a significant impact on task completion.

- **5.14.26 Alert to meaningful events or patterns.** Decision aids should automatically notify the user of meaningful patterns or events such as when it predicts a future problem. [Source: AHCI, 1998]

- **5.15.27 Predict based on historical data.** Decision aids should be able to predict future data based on historical data and current conditions. [Source: AHCI, 1998]

- **5.14.28 Graphic representation.** Decision aids should be able to graphically represent system relationships, its rules network, and reasoning process. [Source: NUREG-0700, 1996]

- **5.14.29 Simulation mode identification.** When decision aids have a simulation mode, entering the simulation mode should require an explicit command and result in a distinguishable change in output. [Source: NUREG-0700, 1996]

- ▪ **5.14.30 Knowledge of intent.** Each element in an intelligent human-machine system shall have knowledge of the intent of the other elements. [Source: Billings, 1996; NRC, 1998; Parasuraman et al., 2000]

  Discussion. Monitoring of the system by the user and the user by the system can only be effective if each knows what the other one is trying to accomplish. [Source: Billings, 1996]

- **5.14.31 Adaptive decision aiding.** When adaptive decision aiding is used, the level of decision aiding should change with the situational demands in order to optimize performance (See section 5.13 on adaptive automation). [Source: Rouse, 1988]

  Discussion. The criticality of a given task can change dramatically depending on the current situation. [Source: Derrick, 1988]

- 5.14.32 **Adaptive decision aiding implementation.** Adaptive decision aiding should be applied when resource loading, performance, error frequency, and deviations from intent exceed threshold levels (See section 5.13 on adaptive automation). [Source: Andes, 1987]

  Discussion. Resource loading, performance, errors, and deviations from intent can be used as indicators to determine when the user might need the help of the automated decision aid. The threshold levels of these indicators, specifying the optimal time to implement decision aiding may need to be determined on a system-by-system basis, possibly through simulation.

- 5.14.33 **Planning assistance.** Adaptive decision aiding interfaces should allow the user to receive direct assistance in planning how to carry out the intended task. [Source: Tyler & Treu, 1989]

- 5.14.34 **User initiated automation implementation.** The user should be able to initiate automated aids even if system-initiated automation is the norm. [Source: Billings, 1997; Harris, Hancock, Arthur, & Caird, 1995]

  Discussion. User acceptance of automation centers on whether the user feels in control of the system. [Source: Rouse, 1988]

5.15 Control automation

Definition. Control automation is when the system executes actions or control tasks with some level of autonomy.

- 5.15.1 **Actions similar to human control.** When automated control actions are performed, the automated tasks should be easily understood by users and similar to user control actions. [Source: Billings, 1991]

- 5.15.2 **Authority limits.** Control automation should not be able to jeopardize safety or make a difficult situation worse. (See 5.1.2.) [Source: AHCI, 1998]

- 5.15.3 **Range of control options.** Automated systems should provide the user with an appropriate range of control options that are flexible enough to accommodate the full range of operating conditions for which it was certified. [Source: AHCI, 1998; Parasuraman & Riley, 1997; Sarter & Woods, 1995]

  Discussion. Highly flexible automated systems can be useful when the user knows how to implement the various options across a wide spectrum of operational situations. However, the multiple options that are associated with highly flexible systems also require additional cognitive resources in order for the user to remember which mode is active. [Source: Woods, 1996]

- ■ 5.15.4 **Immediate feedback.** To promote successful situation awareness of the automated system, the user shall be given immediate feedback to command and control orders. [Source: Morris & Zee, 1988]

- □ 5.15.5 **System flexibility.** Control automation should be flexible enough to allow for different user styles and responses without imposing new tasks on users or affecting automation performance. [Source: Wiener & Curry, 1980; Woods, 1996]

- ■ 5.15.6 **Override and backup alternatives.** Override and backup control alternatives shall be available for automation controls that are critical to the integrity of the system or when lives depend on the system. [Source: Billings, 1991]

- ■ 5.15.7 **Backup information.** Information for backup or override capability shall be readily accessible. [Source: Billings, 1991]

- □ 5.15.8 **Overriding out-of-tolerance conditions.** When a user might need to operate in out-of-tolerance conditions, then a deliberate overriding action should be possible. [Source: Billings, 1991]

  Discussion. There may be cases, particularly in an emergency situation, when the user needs to operate in out-of-tolerance conditions. [Source: Billings, 1996]

GLOSSARY

Automation - a device or system that independently carries out a task that was formerly carried out by a human.

Control automation - when an automated system executes actions or control tasks with some level of autonomy.

Decision aids - (sometimes referred to as decision support systems) automated systems that provide support to human decision-making processes either unsolicited or by user request. Decision aids can narrow the decision alternatives to a few or suggest a preferred decision based on available data.

Direct manipulation - when the user controls the interaction with the computer by acting directly on objects on the display screen. An object may be an icon, menu option, symbol, button, or dialog box. An example of direct manipulation is a GUI.

Mental model - an individual's understanding of the processes underlying system operation.

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